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FUNCTIONAL
TRIFLUOROVINYL MONOMERS
AND THEIR
COPOLYMERIZATION
WITH
FLUOROOLEFINS

Petya Petrova
Bruno Ameduri
Georges Kostov
-and-
Bernard Boutevin

ENGLISH TRANSLATION
OF
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Functional trifluorovinyl monomers and their
copolymerization with fluoroolefins

5 The present invention relates to fluoro-
monomers. It also relates to processes for the
copolymerization of fluoromonomers with fluoroolefins,
to the resulting copolymers and to the use of these
monomers in forming in particular fluoroelastomers. In
addition, the present invention relates to a process
10 for the crosslinking of these copolymers.

A large number of fluoromonomers have already
been disclosed in the literature.

15 The synthesis of fluoroolefins corresponding to
the general formula $\text{CF}_2=\text{CF}(\text{CF}_2)_m(\text{CH}_2)_n\text{OH}$ (with $m = 0$ to
10 and $n = 1$ to 4) is disclosed in Patent Application
EP 0 138 091. The use of fluoroolefins as comonomers of
vinylidene fluoride is also envisaged.

20 Patent Application EP 0 135 917 discloses
fluorocopolymers formed by copolymerization of
vinylidene fluoride with fluoroolefins of general
formula $\text{CF}_2=\text{CF}(\text{CF}_2)_m(\text{CH}_2)_n\text{X}$ (with $\text{X} = \text{OH}$, COOH or an
epoxide group, $m = 0$ to 10 and $n = 1$ to 4). The
copolymerization of some of these compounds with
vinylidene fluoride is described therein.

25 Patent US 3 483 263 discloses the synthesis of
unsaturated haloalcohols corresponding to the formula
 $\text{CX}_1\text{X}_2=\text{CX}_3-\text{A}-\text{OH}$ in which X_1 to X_3 represent halogen atoms
and A represents an alkylene group comprising at least
two carbon atoms.

30 T. Nguyen et al., in J. Organic. Chem., 54(23),
5640-5642, 1989, disclose the synthesis of a compound
corresponding to the formula $\text{CF}_2=\text{CFCH}_2\text{OH}$ by addition of
methyllithium to 2,2,3,3-tetrafluoropropanol.

35 The document SU 375298 discloses the use of
 $\text{CF}_2=\text{CFCH}_2\text{OH}$ in the preparation of O-(2,3,3-
trifluoroalkyl) phosphonates.

The document WO 86/07590 relates to pesticides
corresponding to the general formula $\text{CF}_2=\text{CF}-(\text{CH}_2)_n-\text{X}-\text{R}$
in which X can be O, N, S or CH_2 and n can have the

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values from 1 to 4, the value of R depending on the meaning of X.

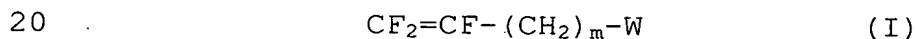
The use of compounds of formula $\text{CF}_2=\text{CF}-\text{CH}_2\text{Q}$ as pesticides is revealed in United States of America Patent US 5 514 717.

W.R. Dolbier et al., in J. Chem. Soc. Perkin Trans., 2, 219-232, 1998, analysed the cyclization activities of hex-5-enyl radicals and disclosed, inter alia, the synthesis of the compound 4,5,5-trifluoropent-4-enol.

T. Dubuffet et al., in J. Organomet. Chem., 341, 11-18, 1998, reveal a process for the opening of oxetanes under the action of fluorinated organolithium derivatives. Test 13 gives access to the compound 4,5,5-trifluoropent-4-enol.

An object of the present invention consists in making available novel fluoromonomers.

This object is achieved by compounds corresponding to the formula I



in which

m has the value 1, 2 or 3,

W represents a $\text{CH}(\text{OH})\text{CH}_2\text{OH}$ group, a $\begin{array}{c} \text{P}-\text{R}_1 \\ | \\ \text{R}_2 \end{array}$ group,

a $\begin{array}{c} \text{O} \\ || \\ \text{P}-\text{R}_3 \\ | \\ \text{R}_4 \end{array}$ group, a $\begin{array}{c} \text{O} \\ || \\ \text{P}-\text{OR}_5 \\ | \\ \text{R}_6 \end{array}$ group, a $\begin{array}{c} \text{O} \\ || \\ \text{P}-\text{OR}_7 \\ | \\ \text{OR}_8 \end{array}$ group or a Y-Z group.

in which

R_1 , R_2 , R_3 and R_4 independently represent a hydrogen atom, a C_1 - C_{20} alkyl group or an optionally substituted aryl group

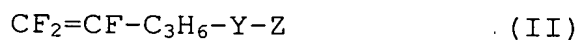
R_5 and R_6 independently represent a hydrogen atom, a C_1 - C_{20} alkyl group or an optionally substituted aryl group, with the proviso that, when R_5 represents a hydrogen atom, R_6 is other than a phenyl group when m has the value 1

R₇ and R₈ independently represent a hydrogen atom, a C₁-C₂₀ alkyl group or an optionally substituted aryl group, with the proviso that R₇ and R₈ do not both represent a hydrogen atom or an ethyl group when m has the value 1

Y represents an oxygen atom or a sulphur atom and
Z represents a hydrogen atom, a CH₂CH₂OH group, a CH₂COOH group or a COCH₃ group,

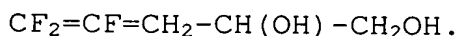
with the proviso that, when W represents CH(OH)CH₂OH, m has the value 1, when Y represents an oxygen atom, Z is not a hydrogen atom and, when Y represents S, m has the value 3.

More particularly, the present invention provides compounds corresponding to the formula II

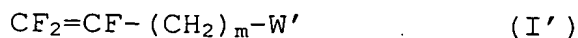


in which Y and Z are as defined above.

Another compound according to the present invention corresponds to the formula



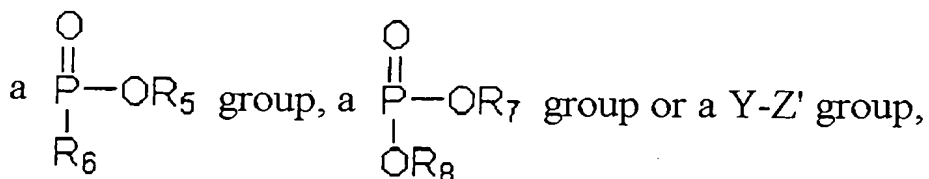
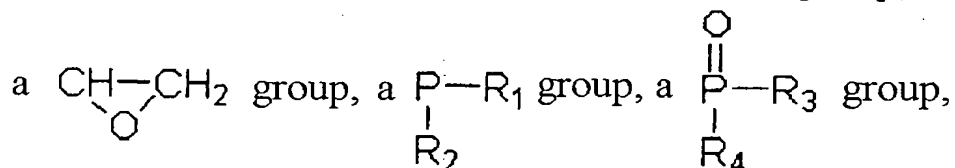
Another object of the present invention is a copolymerization process comprising the reaction of a compound corresponding to the formula I'



in which

m has the value 1, 2 or 3,

W' represents a CH(OH)CH₂OH group, a CH=CH₂ group,

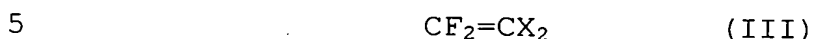


in which

R₁, R₂, R₃, R₄, R₅, R₆, R₇ and R₈ independently represent a hydrogen atom, a C₁-C₂₀ alkyl group or an optionally substituted aryl group

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Y represents an oxygen atom or a sulphur atom and
Z' represents a hydrogen atom, a CH₂CH₂OH group, a
CH₂COOH group or a COCH₃ group,
with a compound corresponding to the formula III



in which

X independently represents a hydrogen atom or a
fluorine atom

with the proviso that, when m has the value 1 and X
represents a hydrogen atom, W' does not represent a
CH-CH₂ group,
O

so as to obtain a fluorocopolymer.

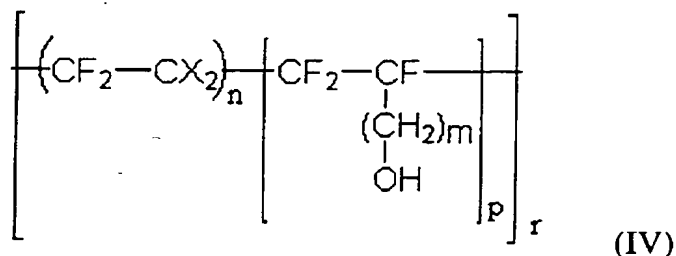
One embodiment of the present invention is a
copolymerization process comprising the reaction of a
compound corresponding to the formula I'
in which

m has the value 1, 2 or 3,

W' represents Y-Z' and Y represents an oxygen atom
and Z' represents a hydrogen atom

with a compound corresponding to the formula III
in which X independently represents a hydrogen atom or
a fluorine atom

so as to obtain a copolymer corresponding to the
formula IV



n, p and r independently representing natural integers.

An additional aspect of the present invention
is a copolymerization process comprising the reaction
of a compound corresponding to the formula I'

in which

m has the value 1, 2 or 3,

W' represents Y-Z' and Y represents an oxygen atom
and Z' represents a COCH₃ group

with a compound corresponding to the formula III

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so as to obtain a copolymer corresponding to the formula V



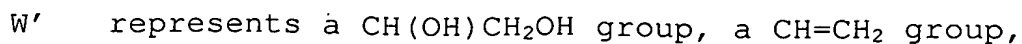
The present invention also envisages a copolymerization process comprising the reaction of a compound corresponding to the formula I'

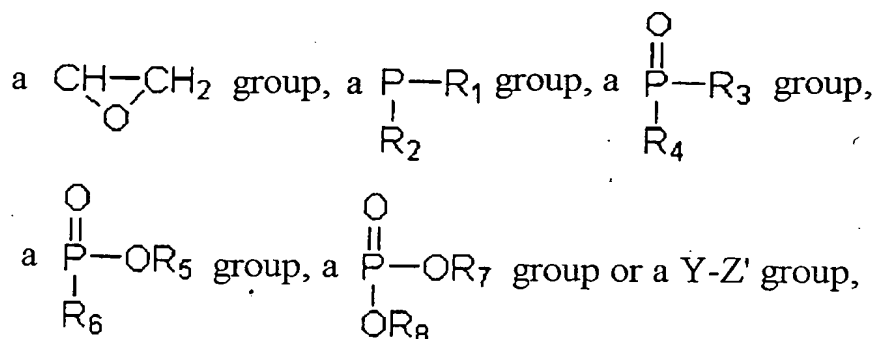
W' represents Y-Z' and Y represents a sulphur atom
and Z' represents a COCH₃ group

15 in which X independently represents a hydrogen atom or
a fluorine atom

$$\left[\left(\text{CF}_2 - \text{CX}_2 \right)_n \left[\text{CF}_2 - \underset{\begin{array}{c} | \\ (\text{CH}_2)_m \\ | \\ \text{S} \\ | \\ \text{COCH}_3 \end{array}}{\text{CF}} \right]_p \right]_r \quad (\text{VI})$$

According to yet another preferred embodiment, a copolymerization process is provided comprising the reaction of a compound corresponding to the formula I'





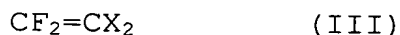
in which

$\text{R}_1, \text{R}_2, \text{R}_3, \text{R}_4, \text{R}_5, \text{R}_6, \text{R}_7$ and R_8 independently represent
a hydrogen atom, a $\text{C}_1\text{-C}_{20}$ alkyl group or
an optionally substituted aryl group

Y represents an oxygen atom or a sulphur atom and

Z' represents a hydrogen atom, a $\text{CH}_2\text{CH}_2\text{OH}$ group, a
 CH_2COOH group or a COCH_3 group,

with a compound corresponding to the formula III



in which

X independently represents a hydrogen atom or a
fluorine atom

and with an olefinic compound
so as to obtain a copolymer.

More particularly, the invention relates to a
copolymerization process comprising the reaction of a
compound corresponding to the formula I'

in which

m has the value 1, 2 or 3,

W' represents $\text{Y-Z}'$ and Y represents an oxygen atom
and Z' represents a hydrogen atom

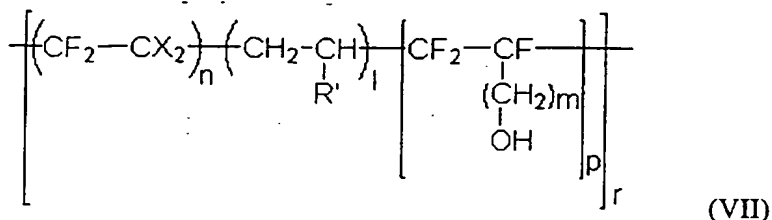
with a compound corresponding to the formula III

in which X independently represents a hydrogen atom or
a fluorine atom

and with an olefinic compound of formula $\text{CH}_2=\text{CHR}'$ with
 R' representing a hydrogen atom or a $\text{C}_1\text{-C}_4$ alkyl group

so as to obtain a copolymer corresponding to the
formula VII

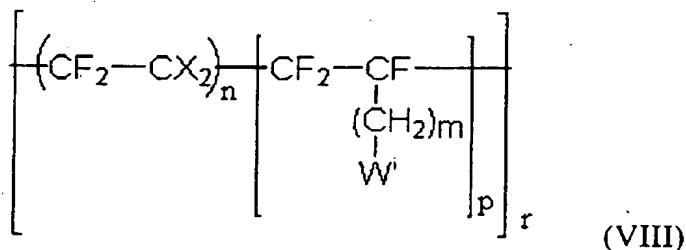
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1, n, p and r independently representing natural integers. Examples of C₁-C₄ alkyl groups are ethylene, propylene and butylene.

5 Fluoropolymers possess outstanding properties, such as their hydro- and oleophobicity, their thermal stability, their chemical inertia to acids, to bases, to solvents and to hydrocarbons, their resistance to ageing and to UV radiation and their low surface
10 tension. They find highly varied applications, often in high-tech industries, such as microelectronics, the chemical industry, the automobile industry, the petroleum industry and the aeronautics industry. However, the high melting and glass transition
15 temperatures of most of these polymers prove to be a limitation on their use which thus requires a significant energy input.

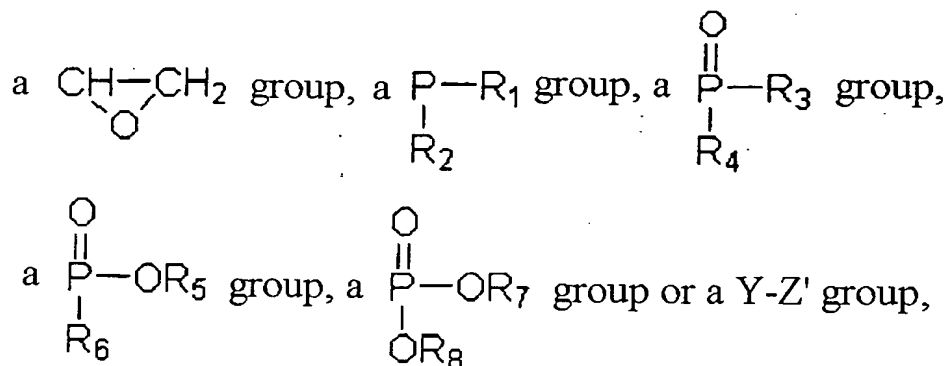
In order to limit this disadvantage, the present invention provides, according to another of its
20 aspects, copolymers corresponding to the general formula VIII



in which

- m has the value 1, 2 or 3,
25 X independently represents a hydrogen atom or a fluorine atom,
n, p and r independently represent natural integers, and
W' represents a CH(OH)CH₂OH group, a CH=CH₂ group,

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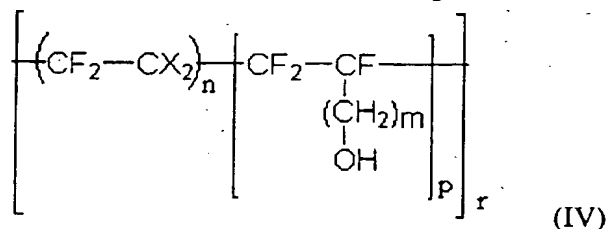
in which

R₁, R₂, R₃, R₄, R₅, R₆, R₇ and R₈ independently represent
a hydrogen atom, a C₁-C₂₀ alkyl group or
an optionally substituted aryl group

Y represents an oxygen atom or a sulphur atom and

Z' represents a hydrogen atom, a CH₂CH₂OH group, a
CH₂COOH group or a COCH₃ group.

More specifically, the present invention
relates to copolymers corresponding to the formula IV



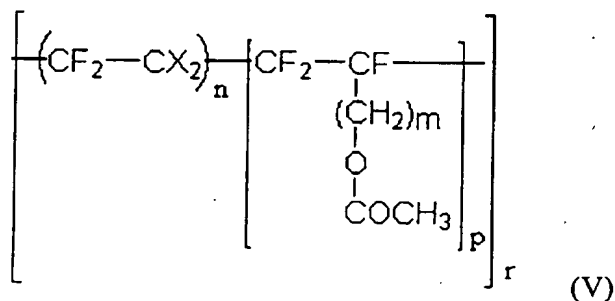
in which

m has the value 1, 2 or 3,

X independently represents a hydrogen atom or a
fluorine atom and

n, p and r independently represent natural integers.

The present invention also relates to
copolymers corresponding to the formula V



in which

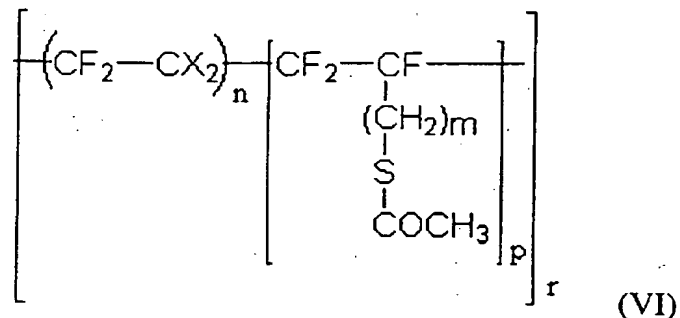
m has the value 1, 2 or 3,

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X independently represents a hydrogen atom or a fluorine atom and

n, p and r independently represent natural integers.

The present invention also relates to
5 copolymers corresponding to the formula VI



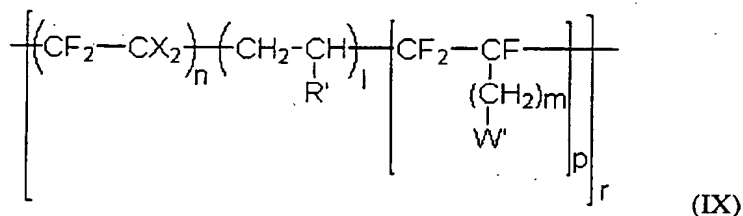
in which

m has the value 1, 2 or 3,

10 X independently represents a hydrogen atom or a fluorine atom and

n, p and r independently represent natural integers.

Other copolymers provided by the present invention are copolymers corresponding to the general formula IX



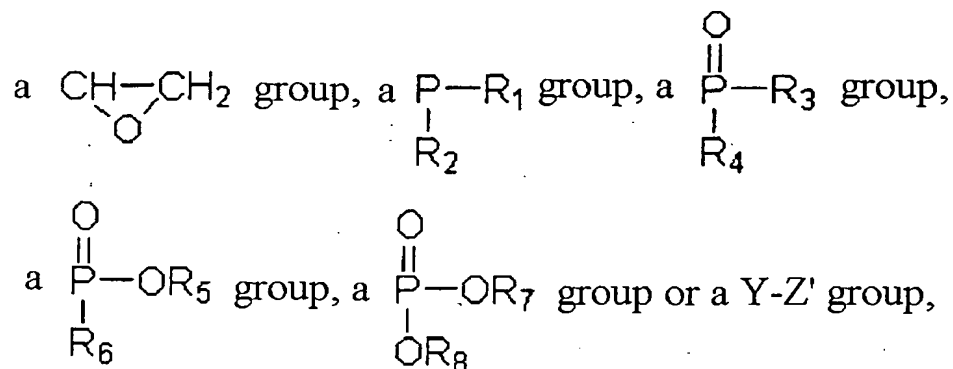
15 in which

m has the value 1, 2 or 3,

X independently represents a hydrogen atom or a fluorine atom,

20 l, n, p and r independently represent natural integers,
R' represents a hydrogen atom or a C₁-C₄ alkyl group and
W' represents a CH(OH)CH₂OH group, a CH=CH₂ group,

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in which

$\text{R}_1, \text{R}_2, \text{R}_3, \text{R}_4, \text{R}_5, \text{R}_6, \text{R}_7$ and R_8 independently represent a hydrogen atom, a $\text{C}_1\text{-C}_{20}$ alkyl group or an optionally substituted aryl group

Y represents an oxygen atom or a sulphur atom and Z' represents a hydrogen atom, a $\text{CH}_2\text{CH}_2\text{OH}$ group, a CH_2COOH group or a COCH_3 group.

More specifically, the present invention provides copolymers corresponding to the formula IX, in which

m has the value 1, 2 or 3,

X independently represents a hydrogen atom or a fluorine atom,

W' represents $\text{Y-Z}'$ and Y represents an oxygen atom and Z' represents a hydrogen atom

l, n, p and r independently represent natural integers and R' represents a hydrogen atom or a $\text{C}_1\text{-C}_4$ alkyl group.

These copolymers comprise monomers exhibiting the $\text{CF}_2=\text{CF-R''-W}'$ structure, R'' denoting a spacer arm of variable length targeted at introducing free volumes and at thus reducing the melting and glass transition temperatures.

In order to further improve the properties (particularly mechanical properties) of these fluoro(co)polymers, it is often desirable to crosslink them but this crosslinking to date has required the use of nucleophilic agents (such as diamines or bisphenols) or of radical systems (triallyl cyanurate radicals) or electron bombardment. Consequently, with the aim of

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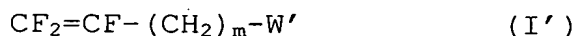
avoiding this additional stage, which constitutes a fairly complex procedure, the present invention provides for the incorporation of crosslinking sites (W' functional group in the above fluoromonomers) directly in the (co)polymers.

An additional object of the present invention is a crosslinking process comprising the stages of

- a) optional deprotection of the functional groups of copolymers obtained above,
- b) reaction of the resulting copolymers with an unconjugated C₅-C₈ diene, so as to obtain crosslinked copolymers.

Examples of unconjugated dienes are 1,4-pentadiene, 1,5-hexadiene, 1,7-octadiene and 1,9-decadiene. The use of 1,5-hexadiene as unconjugated diene is particularly preferred.

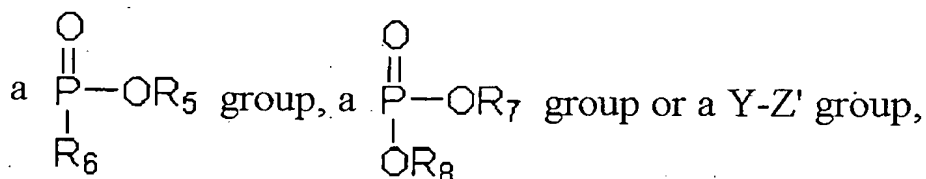
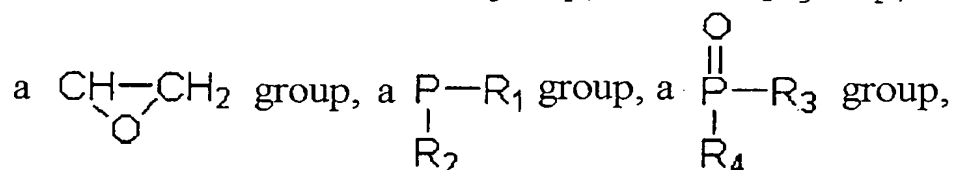
Finally, the use is also provided of compounds corresponding to the formula I'



in which

m has the value 1, 2 or 3,

W' represents a CH(OH)CH₂OH group, a CH=CH₂ group,



in which

- R₁, R₂, R₃, R₄, R₅, R₆, R₇ and R₈ independently represent a hydrogen atom, a C₁-C₂₀ alkyl group or an optionally substituted aryl group

Y represents an oxygen atom or a sulphur atom and

- Z' represents a hydrogen atom, a CH₂CH₂OH group, a CH₂COOH group or a COCH₃ group,

with a compound corresponding to the formula III

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in which X independently represents a hydrogen atom or a fluorine atom, preferably a hydrogen atom and optionally with an olefinic compound, to form 5 fluoroelastomers. Examples of olefinic compounds are ethylene, propylene and butylene. The olefinic compound is preferably propylene.

The invention is described in more detail, without implied limitation, in the following examples.

10 Example 1

Preparation of $\text{CF}_2=\text{CFCH}_2\text{CH}(\text{OH})\text{CH}_2\text{OH}$

- a) Radical addition of iododichlorotrifluoroethane to allyl acetate

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15 A mixture composed of 292.2 g (1.050 mol) of iododichlorotrifluoroethane and of 106.5 g (1.065 mol) of allyl acetate was heated with stirring to 55°C in a three-necked round-bottomed flask equipped with a reflux condenser and a thermometer. 1.4 g (3.5 mmol) of t-butyl cyclohexyl peroxy carbonate were added at this 20 temperature and, after 30 minutes, the addition of an equivalent amount of initiator results in an increase in the temperature of the reaction medium to 70°C. After 30 minutes, an additional 1.4 g of 25 initiator were injected into the mixture and brought about a strong exothermic reaction to 175°C (over 10 seconds) which rendered the crude product colourless, followed by a dark brown mixture. After evaporating the unreacted iodo- 30 dichlorotrifluoroethane and allyl acetate, the product mixture was distilled. Boiling point = 101-105°C/0.2 mmHg (lit. val.: 113°C/2 mmHg or 107-110°C/0.5 mmHg). 236.8 g (0.63 mol) of a dark liquid were obtained 35 (yield = 60%).

- b) Epoxidation

9.0 g (0.16 mol) of potassium hydroxide were introduced into 40 g of hexane in a three-necked round-bottomed flask equipped with a reflux

condenser and a mechanical stirrer. 30.5 g (0.08 mol) of the product resulting from the preceding stage were added dropwise to the mixture at ambient temperature. After completing the addition, the medium was heated to 70°C with stirring. After cooling, the KI precipitate was removed by filtration and the crude product was distilled. 11.95 g (0.057 mol) of a light brown liquid were obtained, boiling point = 53-55°C/23 mmHg (yield = 72%).

4,5-Dichloro-4,5,5-trifluoro-1,2-epoxypentane was produced in a proportion of 95.1%, whereas 5,5-dichloro-4,4,5-trifluoro-1,2-epoxypentane was obtained in a proportion of 4.9%.

c) Synthesis of halogenated 1,2-diol by opening of the epoxide ring

A mixture composed of 5.0 g (23.8 mmol) of 4,5-dichloro-4,5,5-trifluoro-1,2-epoxypentane, 11 ml of demineralized water, 11 ml of dioxane and 4 drops of 12N sulphuric acid was stirred in a single-necked round-bottomed flask equipped with a reflux condenser. The medium was heated at reflux for 12 hours. After the reaction, the dioxane was distilled off and the 4,5-dichloro-4,5,5-trifluoro-1,2-dihydroxypentane was extracted with diethyl ether, dried over sodium sulphate and distilled. Boiling point = 28-30°C/26 mmHg. 4.01 g (17.7 mmol) of a colourless liquid were obtained. Yield = 75% of 4,5-dichloro-4,5,5-trifluoro-1,2-dihydroxypentane.

d) Dechlorination of the 1,2-diol

A mixture of 2.37 g (0.036 mol) of activated zinc in 25 ml of dry DMF was stirred in a two-necked round-bottomed flask purged with argon and equipped with a reflux condenser. The temperature of the medium was increased to 70°C and 3.75 g (16.5 mmol) of 4,5-dichloro-4,5,5-trifluoro-1,2-dihydroxypentane obtained above were added dropwise. After reacting for 16 hours, the crude

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product was cooled to ambient temperature and the unreacted zinc was removed by filtration. The filtrate was treated with 10% HCl and the product was extracted with 1,2,2-trifluorotrichloroethane. After distilling off the solvent, the $\text{CF}_2=\text{CFCH}_2\text{CH}(\text{OH})\text{CH}_2\text{OH}$ was rectified in the form of a colourless liquid (0.88 g, 5.6 mmol, yield = 34%), boiling point = 106-110°C.

Example 2

10 Preparation of $\text{CF}_2=\text{CFCH}_2\text{CH}_2\text{CH}_2\text{SCH}_2\text{COOH}$

a) Photochemical initiation (excess of diene)

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15 A Carius tube comprising 0.055 g (0.3 mmol) of benzophenone, 1.84 g (20 mmol) of thioglycolic acid, 5.00 g (41 mmol) of 1,1,2-trifluoro-1,4-pentadiene and 9.0 g of acetonitrile was cooled in an acetone/liquid nitrogen mixture and degassed under vacuum with 5 freezing/thawing cycles, so as to remove the oxygen. It was subsequently sealed and irradiated under a UV lamp for 16 hours. After the reaction, the tube was frozen in liquid nitrogen and opened, and the solvent and the volatile fractions were evaporated under vacuum (0.01 mmHg). 1,1,2-Trifluoro-6-thiaocten-8-oic acid was distilled first to give 25 1.9 g of a pale yellow liquid. Boiling point = 87-90°C/0.15 mmHg (yield = 44%).

b) Photochemical initiation (threefold excess of thioglycolic acid)

30 A similar test to that indicated above was carried out in the presence of 0.083 g (0.46 mmol) of benzophenone, 8.42 g (91.5 mmol) of thioglycolic acid, 3.72 g (30.5 mmol) of 1,1,2-trifluoro-1,4-pentadiene and 10.0 g of acetonitrile. After the same treatment and after the distillation of 35 the excess thioglycolic acid, 5.29 g of a yellow wax were obtained (yield = 81%), 3,3,4-trifluoro-2,8-dithianonane-1,9-dioic acid..

c) Radical initiation in the presence of azobisisobutyronitrile (AIBN)

5 A stirred mixture composed of 0.049 g (0.3 mmol) of AIBN, 1.5 g (16.3 mmol) of thioglycolic acid, 1.99 g (16.3 mmol) of 1,1,2-trifluoro-1,4-pentadiene and 10 g of acetonitrile was heated at 80°C for 7 hours in a sealed Carius tube. After the reaction and the opening of the tube, the solvent and the unreacted starting materials were evaporated. The brown residue was eluted by flash chromatography on a silica bed with diethyl ether, so as to give an orange oil. The overall yield was 46%. In accordance with the integration of the characteristic signals of the ^1H and ^{19}F NMR spectra, the yields of 1,1,2-trifluoro-6-thiaocten-8-oic acid, of 3,3,4-trifluoro-2,8-dithianonane-1,9-dioic acid and of 4,5,5-trifluoro-6-thiaoctan-8-oic acid were 26, 37 and 37% respectively.

15 A similar experiment, initiated by t-butyl cyclohexyl peroxy carbonate, at 60°C for 5 hours gave 68% of 1,1,2-trifluoro-6-thiaocten-8-oic acid, 7% of 3,3,4-trifluoro-2,8-dithianonane-1,9-dioic acid and 25% of 4,5,5-trifluoro-6-thiaoctan-8-oic acid with an overall yield of 67%.

25 d) Radical initiation in the presence of di-t-butyl peroxide

Under similar conditions to those described above, 500 g (0.04 mol) of 1,1,2-trifluoro-1,4-pentadiene, 3.80 g (0.04 mol) of thioglycolic acid, 30 0.117 g (0.8 mmol) of di-t-butyl peroxide and 10 ml of acetonitrile were reacted. After stirring at 140°C for 6 h and after opening the tube, the solvent was evaporated and the residue was dried at 55°C under 0.1 mmHg to constant weight. A viscous brown liquid was obtained (4.3 g) which is insoluble in chloroform, acetone, DMF, dimethylacetamide, THF and 1,2,2-trifluoroethane. The yield was 49% by mass.

Example 3

Preparation of $\text{CF}_2=\text{CFCH}_2\text{CH}_2\text{CH}_2\text{SCH}_2\text{CH}_2\text{OH}$

The reaction was carried out in a Carius tube comprising a stirred mixture composed of 0.19 g (1.0 mmol) of benzophenone, 2.70 g (34 mmol) of 2-mercaptoethanol, 5.01 g (41 mmol) of 1,1,2-trifluoro-1,4-pentadiene and 9.5 g of acetonitrile. After 6 freezing/thawing cycles, the tube was exposed to UV light at ambient temperature (approximately 25°C) for 14 hours. After a similar treatment, the crude product was purified and the $\text{CF}_2=\text{CFCH}_2\text{CH}_2\text{CH}_2\text{SCH}_2\text{CH}_2\text{OH}$ was distilled. 2.03 g of a colourless liquid were obtained (yield = 29%); boiling point 65-66°C/1 mmHg, 1,1,2-trifluoro-6-thiaoctanol.

Example 4

Preparation of $\text{CF}_2\text{CFCH}_2\text{OH}$

12.4 g (94 mmol) of 2,2,3,3-tetrafluoropropanol, 62.5 ml (367 mmol) of anhydrous dibutyl ether and 9.5 g (94 mmol) of diisopropylamine were placed in a three-necked round-bottomed flask, dried under vacuum and purged with argon so as to remove moisture, equipped with a reflux condenser, a thermometer and a dropping funnel. The mixture was cooled to approximately 0°C. Subsequently, 100 ml (200 mmol) of a 2M solution of butyllithium in pentane were added dropwise for 30 minutes, so as to prevent the temperature from exceeding 5°C. After stirring for 1 hour, the medium was cooled to -50°C in an acetone/liquid nitrogen bath. The excess butyllithium was decomposed using a solution of concentrated sulphuric acid (9.4 ml in 30 ml of water) and the mixture was reheated to ambient temperature. The organic phase was separated by successive rinsings with a saturated sodium hydrogencarbonate solution and with water and then dried over anhydrous MgSO_4 . Subsequently, the products were rectified at atmospheric pressure, so as to separate the pentane (boiling point 35°C), 32 mmol of 2,3,3-trifluoroallyl alcohol (boiling point 98°C) and the dibutyl ether

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(143°C). Even after a second rectification, dibutyl ether was still present in the fluoroalcohol fraction and the yield obtained by ^1H and ^{19}F NMR was 34%.

Example 5

5 Preparation of $\text{CF}_2=\text{CFC}_3\text{H}_6\text{OH}$

a) Radical addition of 1-iodo-1,2-dichlorotrifluoroethane to allyl alcohol

1) Reaction at atmospheric pressure

10 A mixture composed of 171.1 g (0.617 mol) of $\text{Cl}(\text{C}_2\text{F}_3\text{Cl})\text{I}$ and 98.3 g (1.69 mol) of allyl alcohol was stirred in a three-necked round-bottomed flask equipped with a reflux condenser and a thermometer. The mixture was heated to 80°C and 2.30 g (0.014 mol) of AIBN were added
15 thereto every hour. The reaction was monitored by gas phase chromatography (GC) until the iodinated reactant had been virtually completely consumed. Subsequently, the 2-iodo-4,5,5-trifluoro-4,5-dichloropentanol was
20 distilled. 167.5 g (0.497 mol) of an orange-yellow liquid were obtained. Yield = 81%. Boiling point = 64-66°C/0.2 mmHg. 2-Iodo-4,5,5-trifluoro-4,5-dichloropentanol.

2) Reaction carried out in a Carius tube

25 A Carius tube saturated with nitrogen was filled with 40.0 g (0.14 mol) of $\text{Cl}(\text{C}_2\text{F}_3\text{Cl})\text{I}$, with 17.1 g (0.28 mol) of allyl alcohol and with 0.92 g (0.014 mol) of copper powder. The tube was degassed by 5 freezing/thawing cycles
30 and subsequently sealed. It was introduced into an oven incorporating agitation and heated at 120°C for 7 h. After the reaction and cooling to ambient temperature, the tube was frozen in liquid nitrogen and subsequently opened. Once
35 ambient temperature was reached, the crude product was diluted in diethyl ether and the copper was removed by filtration. After an acid treatment, neutralization and evaporation of the solvent, the crude product was analysed by

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GC. The yield was estimated at 62%, 2-iodo-4,5,5-trifluoro-4,5-dichloropentanol.

b) Reduction of 2-iodo-4,5,5-trifluoro-4,5-dichloropentanol

5 80.0 g (0.27 mol) of tributyltin hydride were added dropwise with stirring to 88.9 g (0.26 mol) of 2-iodo-4,5,5-trifluoro-4,5-dichloropentanol placed in a flask, saturated with argon and equipped with a septum, cooled in an ice bath. The addition took 30 minutes, the ice bath having been gradually reduced. The mixture was then stirred for an additional 3 hours at ambient temperature. Subsequently, the reduced derivative, 4,5-dichloro-4,5,5-trifluoropentanol, was
15 distilled under reduced pressure. 47.2 g (0.225 mol) of a light yellow liquid were obtained (yield = 86.5%). Boiling point = 80-82°C/23 mmHg.

c) Dechlorination of 4,5-dichloro-4,5,5-trifluoropentanol

20 100 ml of dry DMF were introduced, via a septum, into a three-necked round-bottomed flask rinsed with a flow of argon and equipped with a reflux condenser. 46.8 g (0.72 mol) of zinc activated by 5 cm³ of acetic acid and 5 cm³ of acetic anhydride
25 were introduced, with vigorous stirring, into the flask and the suspension was heated to 90°C. Subsequently, 50.0 g (0.237 mol) of 4,5-dichloro-4,5,5-trifluoropentanol were added dropwise and the temperature was maintained at 90°C for 4 hours
30 after the completion of the addition. The reaction was monitored by GC, the respective retention times for the trifluorovinyl and chlorinated alcohols being 2.75 and 5.04 minutes respectively. After cooling, the excess zinc was removed by
35 filtration and the crude product was treated with 10% HCl and the fluorinated fraction was extracted with diethyl ether. After distilling off the solvent, the 4,5,5-trifluoropent-4-en-1-ol was rectified. 23.3 g (0.166 mol) of a colourless

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liquid were obtained. Boiling point = 53-55°C/24 mmHg (lit. val.: 95°C/155 mmHg). Yield = 70%.

Example 6

5 Preparation of $\text{CF}_2=\text{CFCH}_2\text{CH}_2\text{CH}_2\text{OCOCH}_3$

31.7 g (0.41 mol) of acetyl chloride were added dropwise to a two-necked round-bottomed flask, cooled in an ice bath, equipped with a reflux condenser (connected to a trap comprising potassium carbonate) and comprising 50.1 g (0.36 mol) of 4,5,5-trifluoropent-4-en-1-ol. The reactivity of the two reactants was monitored by sparging of the trap by HCl. After the completion of the addition, the mixture was stirred at ambient temperature until HCl was no longer being evolved (approximately 4 hours). After distillation, 59.3 g (0.326 mol) of 4,5,5-trifluoro-4-pentenyl acetate (colourless liquid) were obtained. Boiling point = 56-58°C/21 mmHg. (Yield = 91%),

Example 7

20 Copolymerization of trifluorovinyl alcohols with tetrafluoroethylene (TFE)

a) 2,3,3-Trifluoroallyl alcohol (FA1)

The copolymerization in solution (in 34% by weight of butyl ether) of TFE with 2,3,3-trifluoroallyl alcohol was carried out by a batchwise process in 25 30 and 50 cm³ stainless steel autoclaves equipped with a magnetic stirrer, a safety valve, an accurate manometer (± 0.01 MPa) and a thermometer ($\pm 0.2^\circ\text{C}$).

30 The autoclaves were charged with liquid monomer and initiator (AIBN), subsequently cooled with liquid nitrogen and purged several times by placing under a vacuum and by purging with nitrogen via a stainless steel pipe under a high vacuum. The technique of freezing/thawing cycles was used to remove oxygen from the liquid phase. Subsequently, the desired amount of TFE was condensed in the autoclave.

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The polymerization reactions were carried out at various temperatures (60-75°C) under the pressure suitable for TFE to 10-12% conversion of the monomers.

5 After the polymerization, the unreacted TFE was
purged and the comonomers were first recovered by
distillation and subsequently the copolymer was
dried under vacuum (10^{-2} mmHg at 50-60°C) to
constant weight. The reactivity ratios r_i of the
10 comonomers were calculated by the Tidwell and
Mortimer methods and TFE proved to be more
reactive than the monomer FA1 ($r_{FA1} = 0.41$ and r_{TFE}
= 2.47).

b) 4,5,5-trifluoropent-4-en-1-ol (FA2)

15 The bulk copolymerization of TFE with 4,5,5-tri-
fluoropent-4-en-1-ol was carried out by a
batchwise process in 30 and 50 cm³ stainless steel
autoclaves equipped with a magnetic stirrer, a
safety valve, an accurate manometer (± 0.01 MPa)
and a thermometer ($\pm 0.2^\circ\text{C}$).

20 The autoclaves were charged with liquid monomer
and initiator (AIBN), subsequently cooled with
liquid nitrogen and purged several times by
placing under a vacuum and by purging with
25 nitrogen via a stainless steel pipe under a high
vacuum. The technique of freezing/thawing cycles
was used to remove oxygen from the liquid phase.
Subsequently, the desired amount of TFE was
condensed in the autoclave.

30 The polymerization reactions were carried out at
various temperatures (60-75°C) under the pressure
suitable for TFE to 10-12% conversion of the
monomers.

35 After the polymerization, the unreacted TFE was
purged and the comonomers were first recovered by
distillation and subsequently the copolymer was
dried under vacuum (10^{-2} mmHg at 50-60°C) to
constant weight. The reactivity ratios r_i of the
comonomers were calculated by the Tidwell and

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Mortimer methods and TFE proved to be more reactive than the monomer FA2 ($r_{FA2} = 0.45$ and $r_{TFE} = 1.57$).

Example 8

5 Emulsion (ternary) copolymerization of
4,5,5-trifluoropent-4-en-1-ol with tetrafluoroethylene
(TFE) and propylene

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A 250 cm³ stainless steel autoclave (Buchi,
Switzerland) was used as container for the
10 terpolymerization of TFE with propylene and
4,5,5-trifluoropent-4-en-1-ol in a batchwise operation.
The reactor was equipped with a cooling/heating jacket,
with a paddle magnetic stirrer, with a pressure gauge,
with a safety valve and with a measuring unit
15 (monitors of the pressure, stirring and temperature).
The components were prepared separately (solutions A
and B). The TFE/propylene monomer ratio was maintained
at 80/20 mol% (total amount of monomers: 17.7 g) but
the initial percentage of 4,5,5-trifluoropent-4-en-1-ol
20 was varied within the range from 1.7 to 14.1 mol%.

The other components of all the compositions
were as follows: H₂O (125 g); t-butanol^a (36.8 g/l);
Na₂HPO₄·12H₂O^b/NaOH^b = 8/0.8 g/l; C₇F₁₅COONH₄(FC-143)^b
(10.10 g/l). The redox system comprised (mmol/l):
25 t-butyl peroxobenzoate (TBPB)^a (10.30); FeSO₄·7H₂O^b
(0.22); EDTA 2Na·2H₂O^b (0.22); HOCH₂SO₂Na·2H₂O^b (12.70),
where "a" indicates the components of the solution A
and "b" those of the solution B.

The autoclave was closed and the two solutions
30 were purged by a flow of nitrogen. Subsequently, the
reactor was charged with the two solutions under an
inert atmosphere. The amounts of TFE and of propylene
required in order to maintain their initial molar ratio
at 80/20 and the initial pressure at 1.55 MPa for each
35 experiment were introduced into the container while
stirring at 800-850 rev/min. The temperature of the
experiments was maintained by a thermostat at
25 ± 0.2°C. At the end of the copolymerization, the
latex was coagulated by cooling the total product

mixture with liquid nitrogen and the copolymer isolated was dried under vacuum at 60°C to constant weight.

Example 9

Copolymerization of 4,5,5-trifluoro-4-pentenyl acetate (FAC) with vinylidene fluoride (VDF)

Bulk copolymerizations of vinylidene fluoride and of FAC were carried out in Carius tubes made of thick borosilicate in a batchwise process (length: 130 mm, internal diameter: 10 mm, thickness: 2.5 mm, for a total vol of 8 cm³). After having introduced the initiator (0.05 mol% to the mixture of monomers) and the FAC, the tube was connected to a pipe for placing under vacuum and rinsed several times by placing under vacuum and by rinsing with helium. After freezing/thawing cycles, the vinylidene fluoride was trapped under vacuum in the tube frozen with liquid nitrogen, after the reduction in pressure in a calibrated pressure intermediate metal container. The required amount of vinylidene fluoride (0.50-1.00 g) introduced into the tube was obtained by a relative fall in the pressure in this pressure-reducing container fed initially via a 300 g cylinder of vinylidene fluoride.

The tube, under vacuum and immersed in liquid nitrogen, was sealed and placed in the chamber of an oven incorporating agitation at 120°C for 17 hours.

After the copolymerization, the tube was frozen in liquid nitrogen and subsequently opened and the total product mixture was dried at 80°C under 10⁻² mmHg to constant weight.

The composition of the copolymer (that is to say the content of vinylidene fluoride and of FAC in the copolymer) was determined by NMR spectroscopy at ambient temperature. The ¹H and ¹⁹F NMR spectra were recorded on Bruker AC-200 or Bruker AC-250 instruments using deuterated acetone or dimethylformamide as solvents and tetramethylsilane (TMS) or CFC1₃ as internal references, respectively.

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The radical copolymerization of the vinylidene fluoride (VDF) with 4,5,5-trifluoro-4-pentenyl acetate (FAC) was studied over a broad range of initial monomer compositions. ^1H NMR spectroscopy and ^{19}F NMR spectroscopy made it possible to determine the compositions of copolymers and the two results obtained were in good agreement. The reactivity ratios r_i of the comonomers were calculated by the Tidwell and Mortimer methods and the FAC monomer proved to be more reactive than vinylidene fluoride ($r_{\text{VDF}} = 0.17$ and $r_{\text{FAC}} = 3.22$). These values show that a random copolymerization took place. By taking into account the Q and e values of VDF, the Q and e parameters of FAC were calculated: $e_{\text{FAC}} = 1.14-1.23$ (from $e_{\text{VDF}} = 0.40-0.50$) and $Q_{\text{FAC}} = 0.04-0.06$ (in contrast to $Q_{\text{VDF}} = 0.008-0.015$).

Example 10

Copolymerization of 1-thio-4,5,5-trifluoro-4-pentenyl acetate (FSAC) with vinylidene fluoride (VDF)

A 200 ml Hastelloy autoclave, equipped with a valve, a manometer and a safety disc and provided with a magnetic stirrer, was charged with 0.2507 g (1.72 mmol) of *t*-butyl peroxide, with 4.01 g (0.0202 mol) of FSAC and with 70 g of acetonitrile. After being closed, the autoclave was placed in a bath of liquid nitrogen/acetone; subsequently, it was placed under vacuum and purged with gaseous nitrogen, so as to remove the oxygen. 20.25 g (0.316 mol) of vinylidene fluoride were then introduced. After reheating to ambient temperature, the autoclave was introduced into an oil bath with the following heating cycle: 5 h at 120°C, 2 h at 130°C and subsequently 6 h at 140°C. After the reaction, the container was placed in an ice bath and the unreacted vinylidene fluoride was released.

A portion of the acetone of the reaction mixture was evaporated and the vinylidene fluoride/FSAC copolymer was precipitated from a threefold excess of

heptane. The solid polymer was dried at 60-70°C under vacuum to constant weight.

4.36 g of a white solid were obtained (yield of approximately 18%).

5 This powder was soluble in acetone, acetonitrile, DMF and THF at ambient temperature but it was insoluble in cyclohexane, hexane, heptane and toluene, even on heating slightly (40°C).

Example 11

10 Crosslinking of poly(vinylidene fluoride) (PVDF) carrying mercapto functional side groups

a) Hydrolysis of the VDF/FSAc copolymer

15 10 ml of methanol and 10 ml of acetone were introduced into a three-necked round-bottomed flask equipped with a reflux condenser and an inlet for a flow of nitrogen. After degassing and after sparging this mixture with nitrogen, 0.18 g (2.77 mmol) of potassium cyanide and 3.2 g (approximately 1.28 mmol) of VDF/FSAc copolymer were added.

20 The mixture was stirred at ambient temperature for 15 h. After the reaction, the hydrolysed copolymer was precipitated from water. 1.79 g of PVDF carrying mercapto functional side groups were obtained.

25 b) Crosslinking proper

30 A small tube made of borosilicate comprising 1.13 g (0.45 mmol) of PVDF carrying mercapto functional side groups, 1.30 g (15.8 mmol) of 1,5-hexadiene, 0.055 g (0.31 mmol) of t-butyl peroxy-pivalate and 5.04 g of acetonitrile was degassed and purged with helium. Subsequently, after 5 freezing/thawing cycles, it was sealed under vacuum and introduced into an oven with stirring. The tube was stirred for 5 h at 75°C. After the reaction, a beige precipitate appeared at the bottom of the tube. After freezing in liquid nitrogen, the tube was opened. The solvent and the excess 1,5-hexadiene were evaporated and

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the brown solid was dried at 70°C under vacuum for 3 h (1.43 g were obtained). The product was insoluble in polar and nonpolar solvents.

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